Meteorological effects on the noise shielding by low parallel wall structures

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ABSTRACT

Numerical calculations, scale model experiments and real-life implementations have shown that the insertion of a closely spaced array of low parallel walls beside a road is potentially a valuable road traffic noise abatement technique. However, all previous studies have assumed a non-refracting and non-turbulent atmosphere. This study carries out a numerical assessment of the extent to which the noise reduction is preserved in the presence of a refracting and turbulent atmosphere. Several full-wave calculation techniques have been used to model the noise reduction provided by parallel walls subject to moderate and strong winds, and in case of temperature driven turbulence. While meteorological effects do not deteriorate the insertion loss of the parallel wall array in the low frequency range, higher sound frequencies are strongly negatively affected. The numerical results suggest that meteorological effects should be considered when assessing parallel walls as a road traffic noise mitigation measure.

Keywords: Parallel walls, Road traffic noise, Meteorological effects I-INCE Classification of Subjects Number(s): 13.2, 23.4, 23.5, 23.6, 24.5, 24.6, 31.1

1. INTRODUCTION

Although the use of parallel walls for the purpose of road traffic noise abatement can be tracked back to 1982 (1) (only considering peer-reviewed journal papers), there has been a renewed interest in such applications in more recent years (2, 3, 4). The advantages of such a measure are the preservation of the openness of the landscape near the road (in strong contrast to e.g. a traditional noise wall) and its low cost.

Bougdah discussed possible acoustical phenomena when sound waves interact with a parallel wall structure. The cavities formed by the parallel walls could act as quarter-wave length resonators. When regularly spaced, the parallel walls can also be considered as a diffraction grating. Thirdly, diffracted and reflected sound waves in the grooves may interfere. In addition, surface waves will be excited, which, in contrast to the aforementioned effects, always leads to amplification of sound. The latter, however, can be be mitigated by making the walls (partly) absorbing or by partially filling the gaps between the walls with porous medium such as gravel.

The usefulness of parallel walls has been shown by means of scale model studies, real-life implementations and by numerical simulations. So far, only the efficiency in a still and homogeneous atmosphere has been investigated. The fact that the noise reducing mechanisms of such parallel walls are mainly related to interferences, and given that refraction of sound by wind and turbulent scattering will lead to significant phase shifts and amplitude variations, the efficiency of such parallel wall structures should be studied in more realistic atmospheres. This is the main goal of this paper.

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2. NUMERICAL APPROACHES

2.1 Finite-difference time-domain (FDTD) model

The 2D pressure-velocity staggered-in-place staggered-in-time finite-difference time-domain approach (5) is used to solve the linearized equations for sound propagation in a windless and inhomogeneous medium. By using the effective sound speed approach, accurate results are obtained in the case of wind flowing parallel to flat ground (6). A purely logarithmical sound speed profile is used, corresponding to a wind profile characterized by a friction velocity u^* of 0.4 m/s (moderate wind) or 0.8 m/s (strong wind) under a neutral atmosphere. The roughness length is 0.01 m.

Perfectly matched layers are used as reflection free boundaries to simulate the unbounded atmosphere. All other surfaces are rigid, which is efficiently modelled by setting the normal components of the particle velocities to zero where needed.

Scattering by a turbulent atmosphere in FDTD is simulated using the turbule theory as proposed in Ref. (7). The (otherwise uniform) temperature in the sound propagation domain is perturbed, resulting in local variations in the sound speed. Many of such turbulent realizations are generated and sound propagation through each "frozen turbulence" field is explicitly calculated, and energetically summed until convergence is reached at the receiver position.

2.2 Pseudo-spectral time-domain (PSTD) model

The PSTD method (8) is closely related to the FDTD technique. However, this numerical technique is more efficient as only 2 computational cells per wavelength are needed for its spatial discretisation, while phase errors are only introduced by the time iteration scheme. As a result, this model allows 3D applications and this means that sound propagating obliquely over finite length parallel walls could be studied. However, 3D effects will not be discussed in this paper.

Although the effect of wind could be included in more detail by fully solving the Linearized Eulerian Equations (LEE) with both PSTD or FDTD, for the calculations in this paper the effective sound speed approach is used.

2.3 Boundary Element Method (BEM)

The boundary element method (9) is a well-established standard technique solving the Helmholtz equation in the frequency domain. Simulations are limited to sound propagation in a still and homogeneous atmosphere.

3. PARALLEL WALL CASE

3.1 Geometry

The uniform parallel wall configuration studied contains 24 walls, all 0.2 m high and 0.065 m thick, starting at 2.5 m (left face of first wall), with a centre-to-centre spacing of 0.26 m (see Figure 1). The right face of the last wall is positioned at 8.545 m. The source is at (x,z) (0,0.01) m; two receivers are considered, namely at (50,1.5) m and at (50, 4) m. All horizontal and vertical surfaces are rigid.

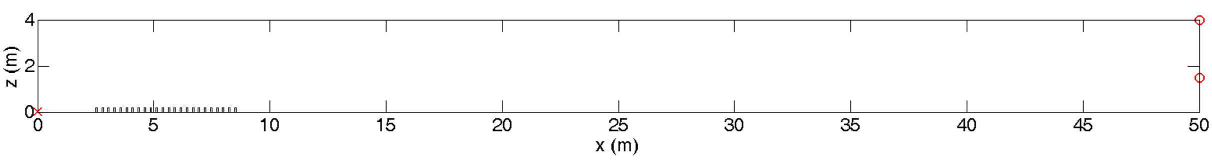

Figure 1 – Parallel wall configuration studied. The red cross indicates the source position, the red open circles the receivers.

3.2 Numerical results

The insertion loss is defined as the sound pressure level in absence of the parallel walls (meaning rigid and flat ground) minus the sound pressure level for exactly the same source and receiver position, and for the same atmospheric condition. It is assumed that the wind flow or temperature turbulence fields are not influenced by the parallel wall structure. In this work, spectral insertion loss graphs will be presented in 1/3 octave bands.

3.2.1 Cross-validation

The comparison in Figure 2 shows that there is a good agreement between the numerical techniques used in this study. Small differences are inevitable, especially since the parallel wall structure under study leads to strong and complex interferences. Furthermore, the sound frequencies considered and the numbers used to constitute the 1/3 octave bands are different for each model.

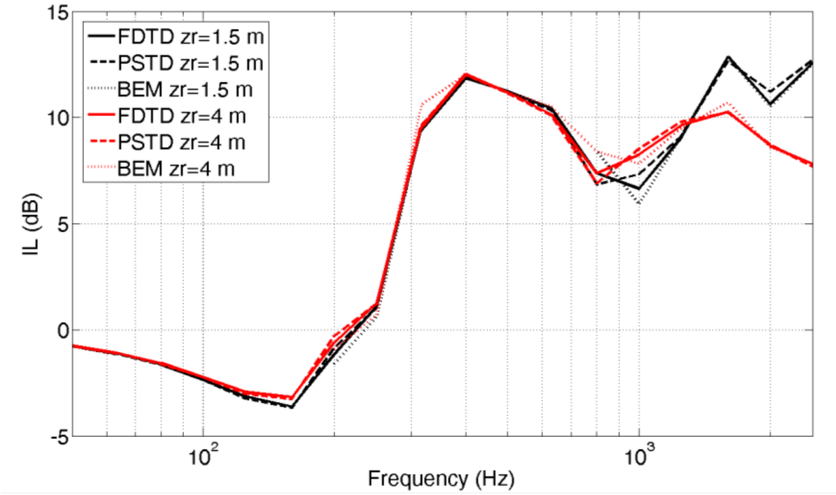

Figure 2 – Parallel wall insertion loss in absence of wind, calculated with FDTD, PSTD and BEM, at the low and high receiver position.

3.2.2 Refracting atmosphere

Predictions assessing the insertion loss of the parallel walls under a refracting atmosphere are depicted in Figure 3. Below roughly 300 Hz, there is almost no influence of the wind. At higher frequencies and with increasing wind speed, the parallel wall shielding strongly deteriorates. Above 1 kHz, an insertion loss of only a few dB remains in case of moderate wind (u^*=0.4 m/s). In case of the strong wind considered here (u^*=0.8 m/s), insertion losses could be even (slightly) negative. In contrast, in absence of wind, insertion losses are near 10 dB in this high-frequency range.

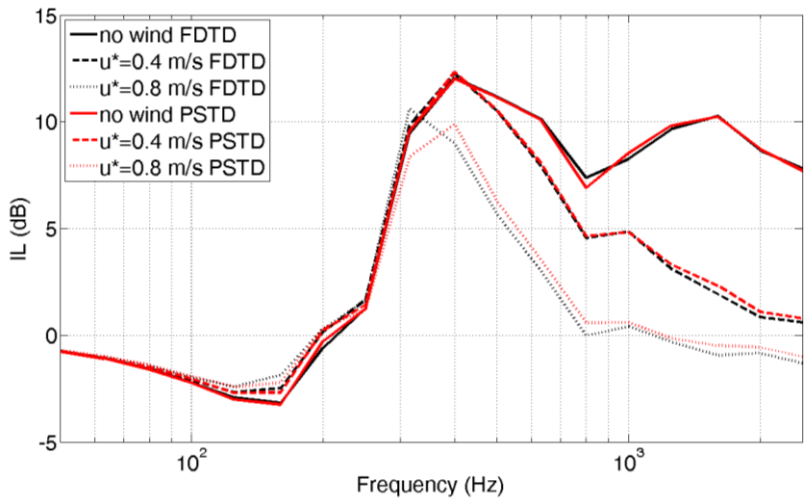

Figure 3 – Parallel wall insertion loss in case of no, moderate and strong wind (at the receiver height of 4 m), calculated with FDTD and PSTD. No turbulence is present.

3.2.3 Turbulent atmosphere

A weakly turbulent atmosphere (C_T^2=0.05 K^2 $m^{-2/3}$) hardly affects the mean insertion loss (see Figure 4). Note, however, that individual 1/3-octave bands could be either positively or negatively influenced, especially at higher frequencies.

In case of much stronger turbulence (C_T^2=2 K^2 $m^{-2/3}$), the mean insertion losses are in general negatively affected. This is not always the case, e.g. at the 315 Hz-1/3 octave band, a statistically significant positive effect in insertion loss is observed relative to a non-turbulent atmosphere.

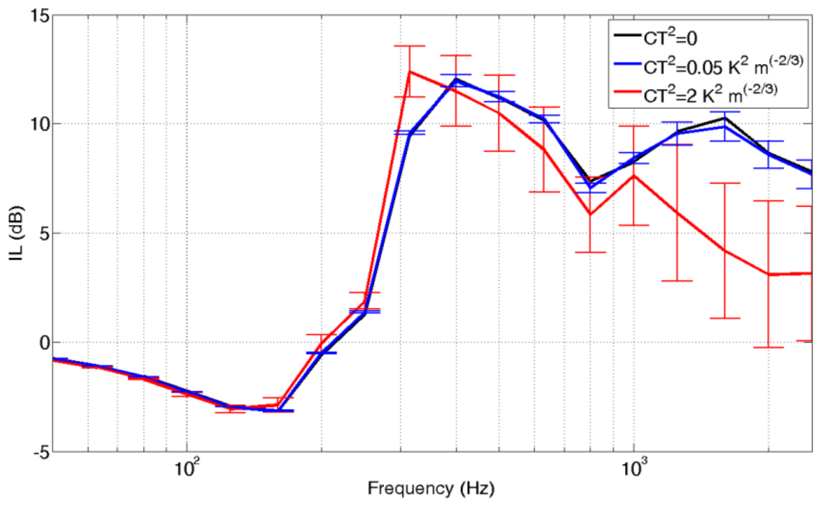

Figure 4 – Parallel wall insertion loss in case of no turbulence, weak turbulence and strong turbulence (at the receiver height of 4 m) in absence of wind (calculated with FDTD). The full length of each error bar represents 2 times the standard deviation on the insertion losses of different turbulent temperature field realisations.

4. CONCLUSIONS

The full-wave techniques used in this work are consistent in their predictions of sound propagating from a low point source over a limited region containing parallel walls towards a more distant receiver. In absence of wind, such a relative small zone of parallel walls along a road is a promising noise abatement technique. However, more realistic predictions including meteorological effects show a strong degradation of its performance in the high frequency range. Note, however, that the efficiency of a conventional noise walls strongly decreases as well under downwind conditions. More research is needed to reveal what type of noise abatement is preferable, including long distance propagation.

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